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Smart Systems in Disposal of Municipal Solid Waste

Valentin Vasilev[1], **Seda H. Bostancı**[2]

[1] Higher School of Security and Economics, Plovdiv, Bulgaria. (e-mail: valentin.vasilev@vusi.bg).
[2] Tekirdağ Namık Kemal University, Department of Political Science and Public Administration, Tekirdağ, Turkey. (e-mail: shbostanci@nku.edu.tr).

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Corresponding author: V. Vasilev
✉ valentinpvasilev1974@gmail.com
☎ +90 899 677 8987

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ABSTRACT

Municipal solid waste disposal, which is generally among the basic duties of municipalities, is the main parameter for citizens' quality of life and their ability to live in healthy environments. A significant payment of the institutions' budgets is allocated for this work. From a service perspective, delays in services such as park and garden landscaping and road works can be partially tolerated by citizens. However, not collecting garbage even for one day can result in citizens reacting negatively to the municipality. In such a critical area that directly affects the quality of urban life, utilizing smart technologies is deemed essential for local governments. In this respect, smart solid waste disposal methods or smart waste management are among the basic components of smart city models. Smart cities use technologies that integrate different services using various technologies such as the internet of things, big data, artificial intelligence, and smart signaling systems. Ensuring waste recycling is among the main goals for smart cities to create healthy environments for sustainable development. Thus, recycling of waste is an important reference point for high quality of life and sustainable urban models. Smart systems used in solid waste disposal are examined in this study. The study used a literature review as a method. Intelligent systems developed for solid waste recycling and disposal methods were examined in the current literature. Research shows that smart systems used in solid waste disposal and recycling techniques produce more effective solutions when adopted by citizens.

1. INTRODUCTION

NOWADAYS urbanization, production cycles, population growth, and changes in lifestyle cause municipal solid waste to increase. Waste is one of the world's primary environmental problems, threatening sustainable development. Problems with waste management create unhealthy urban areas. Various situations, such as developed countries sending their solid waste to developing countries and the location of garbage dumps in poor areas, are ecological injustice problems of the waste issue. The solid waste problem is an issue that developed countries can cope with with innovative approaches, but continues to be a problem area for developing countries [1,2,3]. The multiplier effect of this problem in underdeveloped countries garbage by the fact that waste from developed countries is also moving to these countries. Sending a serious amount of electronic waste, in particular, to Africa creates serious problems for this region [4].

Municipal solid waste is an interdisciplinary field with technical and social aspects. Measures to address the waste problem in urban management include raising awareness among citizens and institutions about waste separation and zero waste, using innovative landfill methods, recycling waste, and implementing integrated waste management within the context of a circular economy. For these purposes, the Internet of Things, sensors, and smart systems are used. Smart waste management is seen as a component of the smart city phenomenon [5-9]. Smart cities support urban quality of life by providing integrated regulations on issues such as electricity, transportation, and logistics through the integration of big data, sensors, and artificial intelligence applications into infrastructure systems. In other words, smart cities are the management systems based on the use of technological capital integrated with e-government systems, including the use of the IoT and IT [10,11].

Definitions of smart cities vary. The application areas of the smart cities are quite broad, and each area has its own fundamental characteristics [12]. In general, there are definitions of core values based on sustainability and democracy; based on technical criteria like data structure; and focusing on service components such as smart transportation and smart infrastructure [13]. Smart cities are closely related to concepts such as digital cities and intelligent cities. Cohen (2012) grouped smart city indicators under six headings: smart people, smart economy, smart environment, smart life, smart management, and smart mobility [14]. These headings also have subheadings. In this assessment, smart living

components were identified as happy, safe, and healthy. While not clear within this approach, the topic of healthy and smart living appears to be most closely related to smart municipal solid waste disposal systems. However, technological innovations, along with smart cities and smart infrastructure systems, have accelerated the development of smart waste management. Smart waste management can contribute to developing waste management scenarios, particularly for situations such as pandemics, natural disasters, and labor strikes.

This study, based on a literature review, examines emerging trends in smart systems in the field of municipal solid waste. From this perspective, the research focuses on innovation in smart technologies that provide convenience and flexibility for municipal waste management.

2. WASTE MANAGEMENT

The planning and implementation of disposal methods for wastes resulting from domestic, industrial and other activities in an environmentally friendly manner, and compatible with recycling systems is defined as waste management. There are various types of waste classification such as domestic wastes, commercial wastes, ashes, animal, construction wastes, industrial solid wastes, biomedical wastes, and hazardous wastes [15-17]. At the same time, wastes are also grouped as recyclable and non-recyclable.

"Waste management systems are evaluated in three main categories: biological methods, thermal systems and sanitary landfills" [17]. I ntegrated solid waste management and zero waste approaches are also current approaches on waste management systems [18,19]. Integrated waste management means that wastes are processed and re-evaluated as resources, becoming components of a circular economy [19,20]. Zero waste management, which can be defined as minimizing waste production to the lowest possible level, is also a sustainable waste management approach. While waste encompasses all solid, liquid, and gaseous state, waste disposal methods primarily focus on solid waste. Although the separation of household waste has become mandatory for households in both developed and developing countries, the disposal of solid waste continues to be a challenging service area for municipalities.

Smart waste management (SWM) involves making the garbage bins within the urban system smart by collecting data with sensors, determining the correct routes of waste trucks to ensure optimization with the data obtained from these, and budget planning for the creation of the technical infrastructure in this area [6]. This approach demonstrates how difficult and costly it is to make waste management systems smart, especially for developing countries. However, applications such as the use of new technologies in landfills and smart city information systems and smart waste collection routes can be seen as a process that every country can overcome. In particular, raising citizens' awareness about waste separation and their transformation into a smart and responsible society is the main element in ensuring a sustainable urban system with a high quality of life.

3. SMART SYSTEMS IN WASTE MANAGEMENT

In this section, various examples of current research on smart systems applied to municipal waste management are included.

Cavdar et al. (2016) implemented an innovative pilot application involving optimization and route determination in waste collection systems [1].

Jayagopal et al. (2020) propose the application of a solar-powered smart solid waste bin by linking smart cities with a smart waste management system [21].

Ali et al. (2020) emphasized the problem of waste materials and proposed an IoT-based smart waste bin monitoring and municipal solid waste management system in their study [7].

Paturi et al. (2021) propose a waste management system that utilizes blockchain and IoT in smart bins. They also note that this system includes a structure that distributes rewards to citizens based on contracts made with them based on user compliance with the system [22].

Moni et al. (2022) proposed an IoT-enabled smart waste management system to detect the level of waste in bins. When waste reaches a certain threshold, an alert message is sent to the relevant authorities, ensuring appropriate waste management measures are taken. This system is designed to save time and contribute to the economy [23].

Henaien et al. (2024) propose a sustainable Smart City Solid Waste Management System (SCSWMS) with next-generation technologies such as low-power wide-area networks, smart traffic systems, and IoT. This system utilizes IoT devices, including smart garbage trucks, real-time user (driver, dispatcher, citizen), and urban route selection and decision support. This application has demonstrated waste collection efficiency and cost reduction [24].

As seen in these examples, innovative smart technologies are being integrated into urban infrastructure and solid waste management at both holistic and design scales.

4. POLICY RECOMMENDATIONS AND FUTURE DIRECTIONS

The success of waste management depends on the development of a sustainable zero-waste society. To achieve such a society, municipalities must regularly implement awareness-raising activities such as education and advertising, starting with primary school. From this perspective, it appears that the issue has become a fundamental area for recycling practices integrated into the circular economy. When waste management is not implemented correctly and effectively, the accumulation of waste increasingly threatens biodiversity and healthy living. A city with a waste problem is unlikely to develop, increase property values, or attract investors. Therefore, while waste management is generally viewed as a technical issue, it is actually closely linked to urban policies.

Waste treatment systems are quite costly. Hidalgo et al. (2019) propose that a creating more ecologically and cost-sustainable waste facility would include treating various waste types, such as municipal, industrial, and biomass, within the same facility, integrating energy and mass into individual waste treatment processes (anaerobic digestion and pyrolysis), and fully recovering wastes, such as biogas, syngas, and carbon pellets, as energy and slow-release fertilizers [20].

Lakhouit (2025) states that technology providers should develop policies that foster collaboration between governments and the public, along with the technical infrastructure, for smart system applications in waste management, and that public participation in the processes should be encouraged. He points out that the use of advanced artificial intelligence and IT technologies in this field will also

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provide advantages in creating healthier environments for future generations [25].

As seen in these approaches, encouraging public participation in the sustainability of innovative solutions in technical processes and promoting the topic are crucial for governments to invest in this area. Behavioral science-based studies on the extent to which citizens recognize smart systems in solid waste disposal will contribute to the development of the social dimension of this field.

5. CONCLUSIONS

This study explores the advantages of using new technologies in municipal solid waste management. The study concludes that the smart city model has not been adequately integrated with smart systems in municipal solid waste management. For example, Cohen's (2012) classification of smart city components, shows that this topic is partially included in the healthy, smart living category [14]. The chaotic environment that results when garbage is not collected for several days in cities is sometimes evident in municipal worker strikes. In this context, the increased emphasis placed on smart waste management by smart cities is a significant step toward a sustainable, healthy future.

When smart systems are not embraced by citizens, their development opportunities are limited. In other words, for sustainability, smart systems must be user-friendly. Smart systems applied to municipal waste management can also measure user and user experiences, as discussed in the study. Thus, the joint contribution of government, citizens, municipalities, and technology developers to the development of this process makes sustainable, healthy urban environments possible.

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BIOGRAPHIES

Valentin Vasilev is a Professor at National Security" (Crisis Situations and Human Resource Management) at the Higher School of Security and Economics /HSSE/, city of Plovdiv and head of the Center for Leadership and Public Policies at the same educational institution.

Seda H. Bostancı who has a primary area of expertise in the field of Local Governments, Urban and Environmental Policies. She has been continuing his academic career as Professor at Tekirdağ Namık Kemal University, Faculty of Economics and Administrative Sciences, Department of Political Science and Public Administration since 2025. She graduated from Mimar Sinan Fine Arts University with a BA in 2000 and an MA in 2002. She completed her doctorate at Istanbul Technical University in 2008.